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Development of High Performance Structural Timver Systems for Non Residential Buildings in New Zealand and Australia

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Abstract

Design of structural systems for commercial and multi-residential buildings throughout most parts of the world, is currently dominated by the use of reinforced and / or prestressed concrete construction, usually supported by steel or concrete beams and frames. However, recent developments throughout the world have demonstrated the potential for timber based structural systems to be used in these types of buildings for beams and columns, roof structures and floors. The advent of engineered wood products (EWP's) such as LVL and glulam has made it possible to fabricate large section, long spanning structural members that have excellent structural properties and reliability equivalent to that of steel or concrete used in the same applications.
Since 2007, significant (and related) research initiatives have been undertaken in Australia and New Zealand, investigating the performance of timber and timber hybrid systems for use in large span / medium rise commercial and industrial buildings. In 2009 a research consortium of government, industry and three Universities known as the Structural Timber Innovation Company (STIC) commenced an extensive R&D 5 year program with a total budget of $10m NZD.
This paper presents an overview of each area of research, describing the focus of work to date, discussion of issues that have been identified and addressed, as well as details of expected outcomes.

Keywords: timber buildings; structural performance; prefabrication.

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1. INTRODUCTION

The vision for the STIC research consortium focuses on the development of innovative large-span timber buildings for a wide range of uses in New Zealand, Australia and other export markets. Primary applications will include commercial, educational, industrial, recreational and residential buildings.

These buildings will have their main structural members manufactured from high quality engineered timber components including glulam (glued laminated timber) and LVL (laminated veneer lumber). The buildings will be from single storey to 6 storeys or more.

The STIC program has been defined with 3 main areas of research: 1) Roof systems and connections; 2) Floor systems; and 3) Wall and Framing systems.

The program as a whole addresses the following performance criteria: Structural performance for serviceability and strength limit states under static loads for commercial / industrial applications; Structural performance for serviceability and strength limit states under dynamic loads, specifically addressing vibration / human comfort criteria; Structural performance for strength limit states under seismic loads; Long term creep / deflection criteria; Acoustic performance; Fire performance; Carbon store / process energy requirements and awareness of thermal mass (operational energy) benefits to meet 5 / 6 star "green building" ratings; and Construction / prefabrication advantages to ensure commercial viability.

2. OBJECTIVES

A major objective for STIC is to create new knowledge and associated technologies that will be "enablers" for a paradigm shift both in the way timber products are manufactured and then utilised by the construction industry in Australia and New Zealand. This necessitates a significant "re-think" for the timber industry – changing the core business model from mass production of generic commodity items (such as timber beams) to value adding, through the development of prefabricated engineered building systems that are innovative and cost competitive alternatives for construction of commercial and industrial buildings.

STIC is targeting sustainable construction, developing new building solutions which greatly reduce environmental impacts. This involves developing a wide range of new high-value structural products, which also add value to lower grade wood products that are part of the total construction package. The initial focus is on large-span, one and two-storey buildings, then moving on to 3 to 6 storey open plan buildings for low seismic areas, then similar or taller buildings for high seismic or high wind areas.

The market drivers pushing development of the new buildings include:

1. Strong international demand for low to medium-rise residential and commercial buildings as a result of demographic changes.
2. Demand for sustainable buildings, renewable materials and reduced CO_2 emissions.
3. Stated government objectives for carbon neutrality in the building industry and wider economy.
4. Industry demand for prefabrication and integrated construction of long-span buildings which can be dis-assembled and relocated at the end-of-life.
5. Increasing importance of rapid reparability and re-use after extreme seismic and weather events.

A key deliverable is the production of comprehensive design guides for designers, regulators, manufacturers and builders. Delivery of the new building systems must be supported by strong relationships with fabricators and construction companies in local and international markets. Buildings will be constructed from prefabricated components, including beams, columns, frames, floors, walls, partitions and cladding panels, manufactured from sawn timber, glulam, LVL, and wood-based panel products, sometimes in composite construction with steel and concrete components.

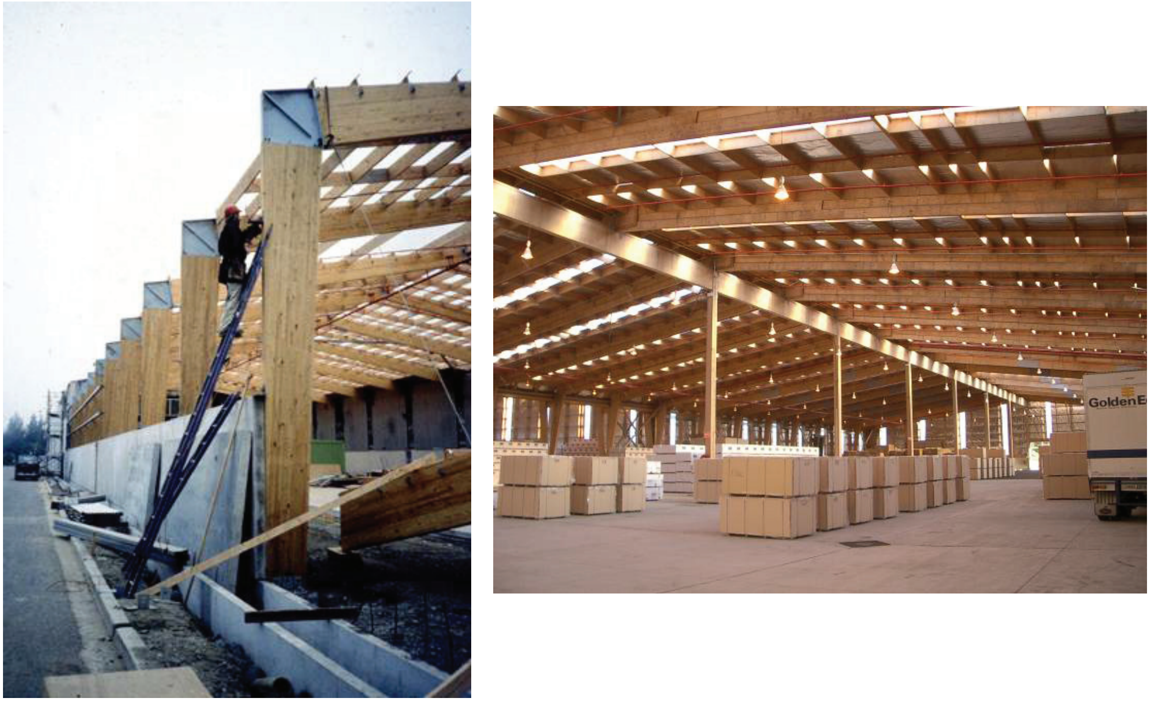

Figure 1: Short-term goal – single storey industrial and commercial buildings

3. RESEARCH THEMES

Prior to the formation of STIC several research projects had been undertaken in Australia and New Zealand that confirmed the findings of a number of international studies, which highlight the lack of timber usage in the non residential building sector, whilst at the same time identifying that there are significant opportunities with the potential to improve market share for the timber industry in commercial and high rise residential construction (Bayne and Taylor 2005). However, a number of specific obstacles where identified that had to be addressed in order to realize this potential – a major one being the need to develop structural systems that can take advantage of prefabrication manufacturing, embody Environmentally Sustainable Design (ESD) principles, are commercially competitive to construct and meet the relevant performance criteria (e.g. structural, occupational safety and comfort, fire and durability) for non residential buildings (Crews et al. 2010).

As a result of this previous work, the fundamental research problem facing the STIC team was “how can we create new markets in Australia and New Zealand for innovative timber building systems, which will allow cost-effective construction of attractive, flexible and durable buildings, with reduced construction time and much lower environmental impacts than traditional construction?” In order to address this issue, the research project was divided into 3 basic thematic areas:

1. Single storey timber roofs and portal frames
2. Floor Systems
3. Wall and Framing Systems

3.1. Objective 1 - Single storey timber roofs and portal frames – 30 to 40m span

Objective Leader: Prof. Pierre Quenneville (University of Auckland). The research question for this theme was: "How can timber materials, fabrication methods, and connection performance be combined so that engineered timber roof structures can compete directly with steel and concrete?" The approach that has been developed has focused on new analytical methods and materials science combined with new connection and construction techniques to make structural systems (members and connections) that are optimized for low cost and rapid erection. The research program is summarized as follows:

3.1.1. New long span roof and portal frame systems

- Assess the benefits of existing timber roofs and portal frame systems.
- Determine optimum structural systems for strength, deformation, speed of construction and cost effectiveness for 30-40 m span timber roofs.
- Analytical investigations and full-scale testing of prestressed LVL and glulam roof systems.
- Prediction of long-term performance of post-tensioned timber beams.
- Identify demonstration buildings that can be monitored for long-term deflections of structural elements using remote sensing. Monitor 2 large-span timber frame buildings.
- Develop analytical procedures and software for manufacturers and designers.

3.1.2. Design of fasteners for large static and dynamic loads

- Investigate the performance of new and existing fasteners in engineered timber materials. Testing of nails, screws, bolts, epoxied rods, and new fastener systems. Statistical analysis.
- Investigate the performance requirements for seismic, wind and gravity loads with unidirectional and cyclic loading, for the life of the structure. Testing in simulated fire conditions.
- New design methods for international acceptance and inclusion in timber design standards.

3.1.3. Connections – develop new portal frame knee joints

- Assess existing systems for moment-resisting timber knee-joints.
- Develop new portal frame knee-joint connections that will enable rapid on-site erection of prefabricated elements in Australia, New Zealand and overseas.
- Undertake full scale testing under static and dynamic loading and develop analytical procedures and design tools on the basis of the test results.

3.2. Objective 2 - Timber floors for multi-storey timber buildings

- Objective Leader: Prof.Keith Crews (University of Technology Sydney). The research question for this theme was: "How can timber materials, fabrication methods, and connection performance be combined so that engineered timber floor systems can compete directly with steel and concrete systems?" The key issues of acoustics and fire performance indicate that the most likely solutions will be concrete-timber composite and stressed skin box beam floor systems. This requires new understanding of time-dependant performance, acoustics and fire performance, with numerical and analytical tools, and new design procedures. The research program is summarized as follows:

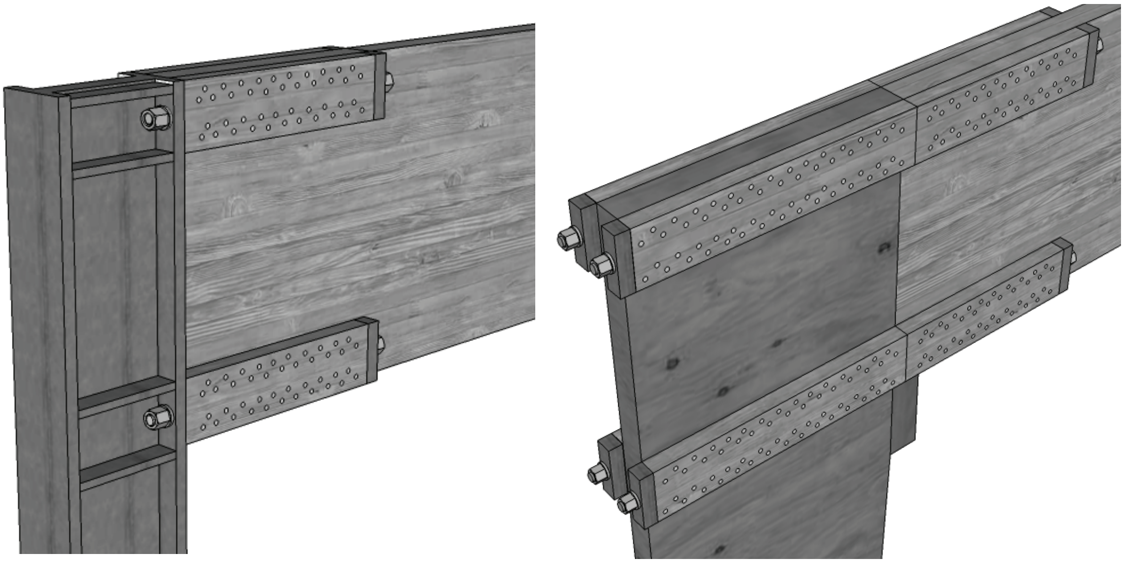

Figure 2: CAD impression of new portal frame connections under development

3.2.1. Floor systems and construction

- Evaluate new and existing floor systems, and create a range of structural timber and composite floor solutions for 6-10m spans.
- Investigate new pre-stressed timber floor systems for spans over 10m.
- Research the best international fabrication and site erection processes for rapid installation, collaborating with industry, fabricators and constructors.
- Develop new analytical procedures to predict the structural performance of composite floors.
- Define optimal construction approaches, design tools and software for fabricators and designers.

3.2.2. Structural performance of floors

- Evaluate a range of new connection systems to achieve adequate shear force transfer and composite action between LVL and concrete. Assess feasible connections.
- Evaluate the materials and structural configurations, and develop computer models to predict the strength, stiffness, dynamics and cost, whilst satisfying the acoustic and fire requirements.
- Investigate alternative decking such as low grade timber and rolled steel profiles. Testing to determine serviceability and strength limit states, dynamic characteristics and creep behaviour.
- Determine in-plane racking performance of floor diaphragms by modelling test data from full scale tests, supplemented by testing of small scale specimens.

3.2.3. Fire resistance

- Survey recent literature on fire resistance of composite floors and determine the failure criteria.
- Investigate fire resistant ceilings and other passive fire protection.

- Full scale fire tests of composite floors at BRANZ.
- Finite element modelling to carry out parametric study on different floor systems.

3.2.4. Acoustic and vibration performance

- Acoustic performance for timber floor systems will be investigated in depth, including flanking noise. Testing of composite floors in demonstration buildings and in the laboratory.

3.2.5. Long term performance

- Investigate the time-dependant performance of timber-concrete composites and carry out long-term creep tests of new floor systems in demonstration buildings.

Figure 3: Testing of Timber Concrete Composite floor beams spanning 8m

3.3. Objective 3 - Multi-storey pre-stressed timber walls and frames

Objective Leader: A/ Stefano Pampanin (University of Canterbury). The research question for this theme was: “What are the main limitations on structural design and construction of large span, high-rise prestressed timber buildings, for long term use and exposure to extreme events?” The main limitations needing scientific research relate to strength and stiffness under earthquake and wind loading, also creep and vibration deformations, fire safety, energy use and sustainability. The research program is summarized as follows:

3.3.1. Structural form and construction

- Identify structural arrangements suitable for 10-20 m beam spans and investigate their pre-stressing anchorage, support and connection details. Tests of strength, stiffness, and ductility.
- Propose procedures for rapid on-site erection of timber frames and walls, and evaluate the suitability of new structural forms and connections, compared with other materials.

- Develop simple and economical standardised structural elements, typical of a prefabricated environment, which can be manufactured in high quantity within a semi-automated process.
- Evaluate the most appropriate and accurate procedures for quantifying and reducing energy use and CO_2 emissions for multi-storey timber buildings.

3.3.2. Structural frames to resist gravity loads

- Identify post and beam systems that will provide gravity support for floors up to 10m span.
- Identify performance requirements for pre-stressed beams. Test under service and ultimate limit state gravity loading, with alternative materials including traditional steel tendons and FRP.
- Extensive testing of beam-column joints to quantify moment, shear and deformation capacity.
- Identify and experimentally evaluate the performance of floor connections to frames and walls.
- Develop analytical and numerical computer models for all tested systems and use these to predict response to extreme loading scenarios with variable material properties.

3.3.3. Fire resistance

- Investigate the growth and spread of fire in multi-storey timber buildings. Develop fire protection strategies for ensuring fire safety in accordance with international fire codes.
- Develop analytical models for predicting the fire resistance of prestressed timber frames and walls, including tendons, anchorages and energy dissipaters. Full-scale tests at BRANZ.

3.3.4. Long term performance

- Measure the time dependant strength and deformation properties of highly stressed timber columns and beams, to predict long term creep performance.

3.3.5. Structural frames and walls for seismic loads and extreme wind loads

- Evaluate the seismic and wind load performance of full-size prestressed timber frames, subjected to combinations of vertical loads and reversed cyclic horizontal loads.
- Evaluate the performance of rocking wall systems using quasi-static and dynamic (shake-table) tests. Develop innovative connection and energy dissipation systems.
- Test full-size 3-D buildings with frames and walls, with and without floor slabs.
- Develop analytical tools for predicting behaviour of all tested systems and methods to allow these to be incorporated into performance-based (displacement-based) design requirements.
- Numerically investigate the seismic performance of alternative seismic resisting systems (frames, walls, dual systems) under far-field or near-field earthquake recorded strong motions.
- Evaluation of higher mode effects, soil-structure interaction, diaphragm action and connections.

4. CONCLUSIONS

The significant support of industry has focused the research methodology to produce useable short term outcomes and prototype buildings, as an integral part of the R&D programs. This has led to implementation of a number of the technologies after only 2 years of work, as can be seen in the building under construction at Nelson in NZ (Figure 4) during May 2010.

Figure 4: A new 3 storey commercial building with timber framing and floor systems

Clearly much more work is required to be able to achieve the target objective of significant penetration into building markets that are currently dominated by steel and concrete materials. However, there is also no doubt that this work and other initiatives in Europe and North America will provide the basis for innovative multi-storey buildings constructed from renewable, environmentally sustainable, engineered timber building solutions in the future.

5. ACKNOWLEDGMENTS

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